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PILOT-SCALE COMBUSTION EVALUATION OF POPLAR RIVER LIGNITE

PHASE II: CONTROL OF SULPHUR DIOXIDE EMISSION USING DRY LIME ADDITION

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Pilot-Scale Combustion Evaluation of Poplar River Lignite, Phase II: Control of Sulphur Dioxide Emissions by Dry Lime Addition

by

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In the final phase of a joint Saskatchewan Power Corporation-CANMET lignite evaluation project, a 5-tonne sample of Poplar River lignite was burned in a pulverized-fired, pilot-scale research boiler to determine the effectiveness of lime additions together with excess combustion air in reducing sulphur dioxide emissions.

The addition of ½% wt lime to the fuel had no effect on the SO_2 emissions whereas a 1% wt addition with 5% O_2 in the flue gas decreased SO_2 emissions below the theoretical level by over 48%; at this condition 25% of the lime input was utilized in neutralizing sulphur.

The addition of 1% wt of lime to the fuel had no measurable effect on combustion characteristics, ash-fouling behaviour low temperature corrosion potential or electrostatic precipitator performance.

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CONTENTS

Page

Abstract i

Contents ii

Introduction 1

Theoretical Considerations 1

Experimental Procedure 2

Fuel Preparation 2

Experimental Data and Discussion 2

Sulphur Dioxide Emissions 3

Lime Utilization 3

Low Temperature Corrosion 4

Fly-Ash Characteristics 4

Fireside Deposits 4

Conclusions 5

References 5

TABLES

No.

1. Analysis of Poplar River Lignite 6
2. Experimental Combustion Conditions 7
3. The Effect of Lime Addition on SO_2 Concentrations 8
4. Lime Utilization during SO_2 Neutralization 8
5. Fly-Ash Loadings and Electrostatic Precipitator Efficiency 9
6. Analyses of the Low-Temperature Corrosion Probe Deposits 10
7. Analyses of Furnace Deposits from Poplar River Lignite 11
8. Analyses of Furnace Deposits from Poplar River Lignite with ½% CaO Addition 12

9. Analyses of Furnace Deposits from Poplar River Lignite with 1% CaO Addition 13

FIGURES

No. Page

1. The Experimental Pilot-Scale Boiler 14

2. The Effect of Lime Addition on Sulphur Dioxide Neutralization 15

3. Fly-Ash Loadings in the Combustion Products 16

4. The Effect of Flue Gas Oxygen Content on the Thermal Penalty from Carbon in Fly-Ash 17

5. The Effect of Lime Addition in the Fusion Characteristics of Deposits throughout the Boiler 18

INTRODUCTION

At the request of the Saskatchewan Power Corporation, the Canadian Combustion Research Laboratory has undertaken a two-part project to evaluate the combustion, fouling and pollutant emissions characteristics of Poplar River lignite. This newly developed lignite deposit is the fuel source for a 1200 MWe thermal electric generating station, recently constructed near Coronach, Saskatchewan.

Part I of the project, an evaluation of the combustion characteristics, fouling and corrosion potential, and atmospheric emission levels of the raw fuel was reported previously (1). The present report, which describes Part II of the project, evaluates the reductions in sulphur dioxide emissions that were obtained by progressively increasing both lime additions to the coal and excess combustion air levels. It also includes an assessment of the effect of the lime additions on combustion efficiency, steaming rate, severity of ash fouling and electrostatic precipitator performance.

THEORETICAL CONSIDERATIONS

In many combustion processes the fixation of sulphur by alkali and alkaline-earth metal ions, normally present in coal ash, can significantly reduce the SO_2 emissions to atmosphere. In extreme cases, this reaction can reduce theoretical gas-phase sulphur oxide emissions by as much as 80%. When the alkali metal ions are not abundant or are present in stable inorganic structures, the neutralization of SO_2 can be enhanced by the use of alkaline minerals such as lime, limestone and dolomite (2). The efficiency of SO_2 removal, however, is dependent on the physico-chemical properties of the mineral added and on the nature of the coal.

EXPERIMENTAL PROCEDURE

The research boiler, illustrated in Figure 1, and the experimental procedures used in Part II were unchanged from those used in Part I of the project (1).

The quality of the Poplar River lignite provided for these experiments, summarized in Table 1, was slightly different than of that provided for Part I. It was necessary, therefore, to establish baseline SO_2 concentrations at excess oxygen levels of 1%, 3% and 5% for this coal without lime addition before proceeding with two series of combustion experiments with lime addition rates of ½% wt and 1% wt of fuel.

During the combustion experiments at least three SO_2 measurements were made at each excess-air level with particular attention being paid to both the batch sampling of SO_2 and the subsequent analysis by the standard West-Gaeke methodology. All SO_2 samples were of one half hour duration and were taken after steady-state operating conditions had been achieved.

For the lime addition trials, one-tonne batches of lignite were blended with pebble lime(minus 3 mm) in a rotary riffle to ensure a uniform distribution of the lime throughout the fuel. The fuel input in each experiment was kept constant at approximately 180 kg/hr and the operating parameters measured during each 8 hr trial, are shown in Table 2. These were essentially the same as those measured during Phase 1 and Phase II.

EXPERIMENTAL DATA AND DISCUSSION

Throughout the lime addition experiments the Poplar River lignite handled and pulverized easily, and flame stability was as good as reported previously (1). Following each combustion experiment, samples of fireside deposits from five different locations throughout the boiler were selected for chemical analysis and ash fusion determinations.

Sulphur Dioxide Emissions

The SO_2 concentrations measured in each combustion experiment are presented in Table 3 and Figure 2; no sulphur trioxide was detected during any of the combustion experiments.

The experimental results show that the neutralization of SO_2 was increased by addition of 1% by wt of lime to the fuel, whereas a ½% wt addition of lime had no effect.

Apparently, small variations in the alkali metal components in the coal ash are sufficient to mask the additional meutralization effects of lime at addition rates below ½% wt.

The results at 1% wt lime addition showed an increase in SO_2 neutralization with increasing partial pressure of oxygen i.e. excess-air level. With 1% wt lime addition to the fuel and nominal excess-combustion-air levels corresponding to oxygen partial pressures of 1%, 3% and 5% in the flue gas, the degree of SO_2 neutralization increased from 39% to 41% to 48.5% respectively. The degree of sulphur neutralization due to indigenous cations in the raw lignite was about 32% for all three oxygen levels.

Lime Utilization

By assuming a general reaction of the form:

$$2CaO + 2SO_2 + O_2 \rightarrow 2CaSO_4$$

the lime utilization with 1% wt lime in the coal was calculated to be 14.7%, 15.9% and 24.6% at excess oxygen levels of 1%, 3% and 5% respectively as shown in Table 4. This suggests that complete elimination of the SO_2 will require a minimum lime addition rate of 2% which corresponds to an atomic ratio Ca:S = 3:1. The sub-stoichiometric lime reactivity observed in these tests may have been affected by calcination temperatures during lime production. It has been reported (2) that a dead burnt lime with its consequent low porosity has a low reactivity with respect to SO_2. In addition, flame temperatures are significantly above the 900 - 1000°C equivalent temperature range where SO_2 absorption is at a maximum;

reduction in lime surface area due to sintering in the flame can reduce the reactivity of the lime.

Low-Temperature Corrosion

The water-soluble components in the inner deposit layer did not show any consistent trends in composition which could be attributed to the additive. Although water-soluble sulphate was identified in all deposits, the amounts of water-soluble iron, sodium and potassium indicate that no free sulphuric acid was present. Since neither an acid dew point nor SO_3 was detectable in any of the experiments it can be concluded that the low-temperature corrosion potential of this lignite was too low to be significantly modified by the addition of up to 1% wt of lime.

Fly-Ash Characteristics

The fly-ash loadings in the flue-gas during each of the combustion tests are shown in Figure 3 and Table 5.The consistently high fly-ash loadings, which were recorded at the highest excess-air level, are probably due to the increased gas velocities which in turn minimized gravity settling of dust throughout the boiler. The lime additive experiments showed consistently lower thermal penalties due to unburnt carbon in the fly ash than those measured during the combustion and fouling investigation (1). This is most probably due to changes in the coal quality. The addition of limestone did not affect this thermal penalty.

The performance of the laboratory electrostatic precipitator did not change as the neutralisation of the SO_2 was increased by lime addition.

Fireside Deposits

The analysis of the fireside deposits collected at different locations in the boiler are given in Tables 7, 8, and 9. All deposits were lightly sintered, friable and easily removed with no evidence of slagging.

The deposits showed generally higher calcium contents as the lime addition rate was increased. This did not, however, have a major effect on

either the ash fusion characteristics of the deposits, as shown in Figure 5, or on the ash fouling characteristics of the fuel.

CONCLUSIONS

Sulphur dioxide neutralization during the combustion of Poplar River lignite was increased from 33% to over 40% by the addition of 1% wt of lime to the fuel. The extent of neutralization increased with increasing excess-air level reaching 47% at 25% excess air.

The addition of 1% wt of lime to the fuel did not affect the combustion, ash fouling and low-temperature corrosion characteristics of the lignite. Electrostatic precipitator performance also remained essentially unchanged.

The addition of ½% by wt lime to the fuel had no apparent effect on SO_2 emissions because small variations in the alkali or alkaline earth cations in the raw lignite tended to mask small increases in sulphur neutralization.

At the three nominal excess-air levels corresponding to oxygen partial pressures of 1%, 3% and 5%, the lime utilization was 14.7%, 15.9% and 24.6% with 1% wt of lime in the fuel. Increased utilization of lime by gas-phase sulphation can probably be achieved by using a more reactive form of calcium.

REFERENCES

1. Lee, G.K. and Brown, T.D., Pilot scale combustion trials with Poplar River lignite, Part I, Combustion performance and fouling characteristics; CANMET, Laboratory report ERP/ERL (CF) 74-41 (IR); 1974.

2. Tennessee Valley Authority; Sulphur oxide removed from power plant stack gas - sorption by limestone or lime, dry process; PB 178972; 1968.

TABLE 1

Analysis of Poplar River Lignite

Proximate Analysis %	
Moisture	12.91
Ash	17.30
Volatile Matter	33.23
Fixed Carbon	36.56
Ultimate Analysis (%,moisture free)	
Carbon	56.39
Hydrogen	3.69
Sulphur	0.69
Nitrogen	0.76
Ash	19.86
Oxygen	18.61
Califoric Value	
Gross: Btu/lb	7942
Ash Fusion Characteristics, °C or Calories/g	
Initial Deformation	1266
Softening	1288
Hemispherical	1338
Fluid	1416

Btu/lb x 0.5556 = Cal./g

TABLE 2

Experimental Combustion Conditions

Operating Parameter / Fuel	Fuel Rate kg/hr	O_2 in Flue Gas %	CO_2 in Flue Gas %	CO in Flue Gas ppmm	Steam Flow kg/hr
Poplar River Lignite	157.2	1.0	18.9	100	695
		3.1	16.6	90	660
		4.7	16.5	55	661
Poplar River Lignite And ½% CaO	151	1.1	18.6	160	693
		3.1	16.8	160	659
		4.9	15.5	110	643
Poplar River Lignite And 1% CaO	162	1.0	17.9	140	704
		3.0	16.6	165	702
		4.9	14.9	105	682

TABLE 3

The Effect of Lime Addition on SO_2 Concentrations

Excess Oxygen % Vol	Sulphur Dioxide Concentration ppm			
	Maximum Theoretical Conversion	Limestone Addition		
		0% wt	½% wt	1% wt
1	1068	715	712	609
3	960	664	672	561
5	850	577	563	436

TABLE 4

Lime Utilization *during SO_2 Neutralization

Excess Oxygen Level	Experimental Condition	Gas Phase SO_2 concentration ppm	Neutralization g/kg Fuel	Utilization* %
1%	Theoretical	1068		
	0% Lime	715		
	½% Lime	712	0	0
	1% Lime	609	0.8	14.74
3%	Theoretical	960		
	0% Lime	664		
	½% Lime	672	0	0
	1% Lime	561	0.9	15.92
5%	Theoretical	850		
	0% Lime	577		
	½% Lime	563	0.1	4.90
	1% Lime	436	1.4	24.62

* This is defined as $\frac{\text{Sulphur neutralization due to lime g/kg Fuel}}{\text{Theoretical maximum neutralization capacity of lime}} \times 100$

TABLE 5

Fly-Ash Loadings and Electrostatic Precipitator Efficiency

Lime Addition Rate	% Oxygen in Flue Gas	Fly-Ash Loadings		Precipitator Efficiency %
		Before Precipitator	After Precipitator	
None	1	6.51 ± 0.33	0.480	89.6 ± 2.8
	3	5.98 ± 1.16	0.596	92.6 ± 0.5
	5	9.84 ± 1.61	0.550	94.3 ± 1.3
½% wt/wt	1	6.45 ± 0.61	0.735	88.5 ± 1.8
	3	5.91 ± 0.65	0.671	88.5 ± 1.6
	5	10.11 ± 1.73	0.731	92.6 ± 1.8
1% wt/wt	1	7.28 ± 1.53	0.710	89.8 ± 3.0
	3	7.38 ± 1.17	0.726	89.9 ± 2.2
	5	10.87 ± 2.62	0.800	92.2 ± 2.7

TABLE 6

Analyses of the Low-Temperature Corrison Probe Deposits

	Probe Temperature ^{o}C	Water Soluble Components in the Low-Temperature Deposits: Accumulation in mg/hr				
		SO_4	Fe	Mg	Na	Ca
Poplar River Lignite	105	0.51	0.12	0.00	0.00	0.19
	121	0.48	2.74	0.00	0.01	0.30
	138	0.45	0.32	0.08	0.03	1.27
Poplar River Lignite + ½% CaO	105	1.33	2.53	0.02	0.03	0.42
	121	0.66	0.12	0.01	0.02	0.99
	138	1.05	0.25	0.00	0.01	0.63
Poplar River Lignite + 1% CaO	105	0.35	0.17	0.01	0.02	0.45
	121	0.48	0.08	0.01	0.02	0.49
	138	0.32	1.80	0.01	0.01	0.43

TABLE 7

Analyses of Furnace Deposits From

Poplar River Lignite

Components	Furnace Bottom	Furnace Wall	Super - heater	Air Heater
Water-Soluble wt%				
Total	4.50	12.0	11.85	6.9
S (as SO_4)	1.60	1.60	5.40	2.10
Fe	0.07	0.07	0.04	0.03
Mg ite	0.10	trace	0.15	0.10
Na	trace	trace	trace	trace
K	-	-	-	-
Ca	1.00	0.30	1.30	0.20
Acid-Soluble wt%				
Fe	2.6	3.9	3.6	3.1
Mg	1.4	2.2	2.8	3.1
Na	0.1	0.2	0.4	0.2
K	0.1	0.5	0.6	0.5
Ca	7.1	7.6	8.0	8.7
Acid-Insoluble wt%	67.5	52.1	47.6	48.6
Deposit Fusion Temperatures,				
Initial Softening	1277	1277	1243	1260
Spherical	1304	1304	1271	1293
Hemispherical	1348	1338	1316	1327
Fluid	1482	1427	1404	1399

TABLE 8

Analyses of Furnace Deposits from Poplar River Lignite

with ½% CaO Addition

	Furnace Bottom	Furnace Wall	Screen Tubes	Super-heater	Air Heater
Water Soluble % wt	3.3	7.4	9.0	9.9	6.5
SO_4	1.5	4.5	4.1	3.9	1.8
Fe	0.0	0.0	0.0	0.0	0.0
Mg	T	T	T	T	T
Na	T	0.1	0	T	T
K	0.0	0.0	0	0.0	0
Ca	1.1	1.9	5.1	5.0	2.4
Acid Soluble % wt	6L				
Fe	2.3	2.6	2.7	2.3	2.6
Mg	1.7	1.2	3.2	3.1	2.3
Na	0.2	0.3	0.4	0.4	0.2
K	0.1	0.2	0.4	0.4	0.2
Ca	6.7	2.2	11.8	9.8	6.8
Al	4.7	3.8	6.4	5.2	5.2
Acid Insoluble % wt	64.6	51.0	45.2	47.8	61.4
Deposit Fusion Temperatures, °C					
Initial Softening	1300	1266	1252	1260	
Spherical	1366	1277	1268	1293	
Hemispherical	1404	1304	1313	1316	
Fluid	1443	1399	1441	1454	

TABLE 9

Analyses of Furnace Deposits from Poplar River Lignites with 1% CaO Addition

	Furnace Bottom	Furnace Wall	Screen Tubes	Super-heater	Air Heater
Water Soluble % wt	5.3	5.4	4.4	12.1	4.7
SO_4	2.3	4.0	0.3	3.9	1.2
Fe	1.5	0.9	0.1	0.4	0.3
Mg	0.1	T	T	T	T
Na	0.06	0.04	0.04	T	0.05
K	0.3	0.02	0.03	T	0.03
Ca	0.2	0.2	0.2	0.2	0.8
Acid Soluble % wt					
Fe	0.6	2.9	2.8	1.2	4.0
Mg	0.4	2.6	1.9	1.4	2.3
Na	0.1	0.4	0.2	0.4	0.3
K	0.1	0.5	0.4	0.6	0.4
Ca	1.8	12.4	7.8	10.0	10.2
Acid Insoluble % wt	36.0	48.0	59.3	38.8	56.9
Deposit Fusion Temperatures, °C					
Initial Softening	1254	1260	1238	1238	1250
Spherical	1277	1293	1276	1243	1276
Hemispherical	1310	1348	1340	1260	1304
Fluid	1387	1410	1360	1343	1360

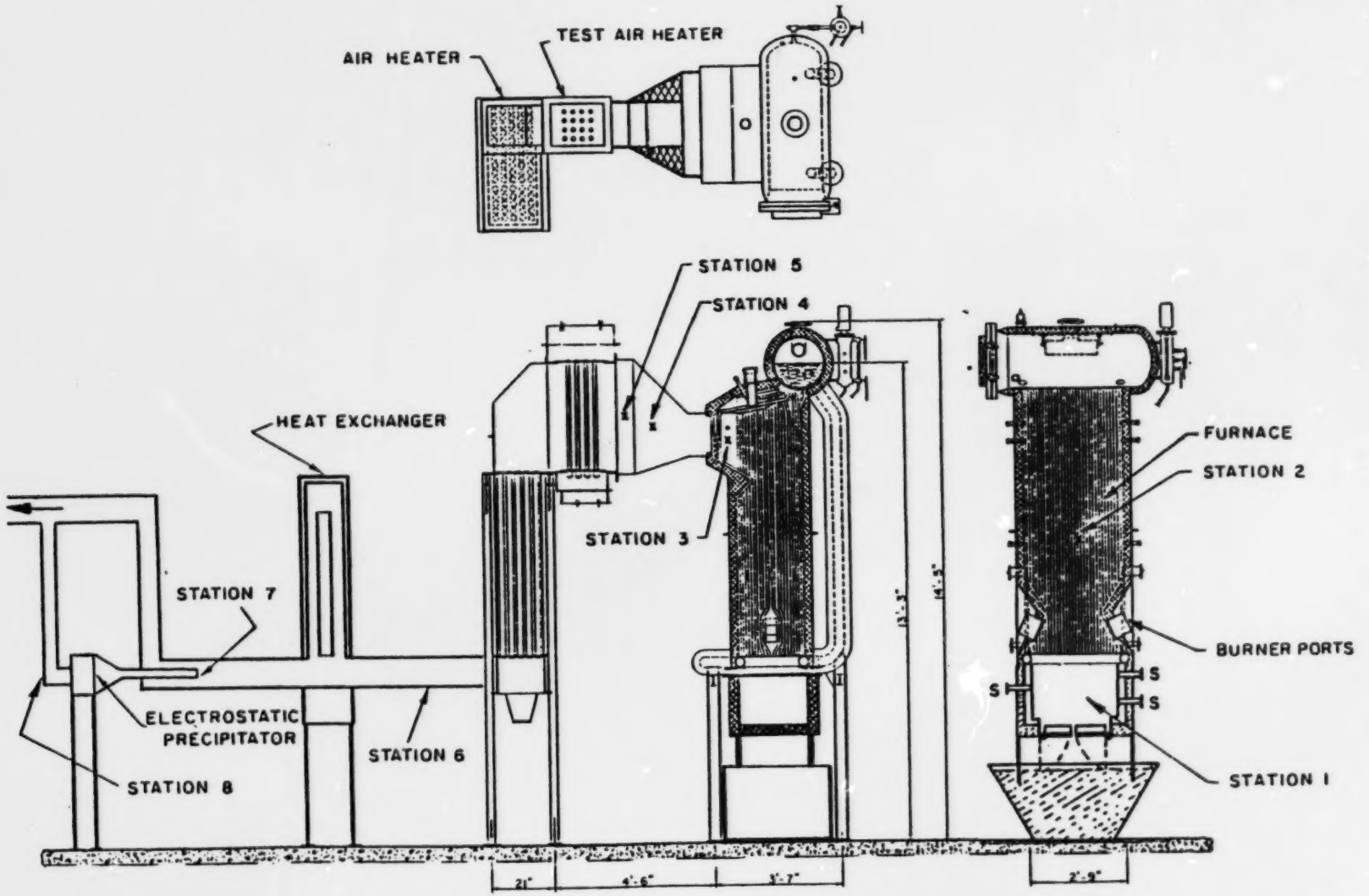

Fig. 1 The Experimental Pilot-Scale Boiler

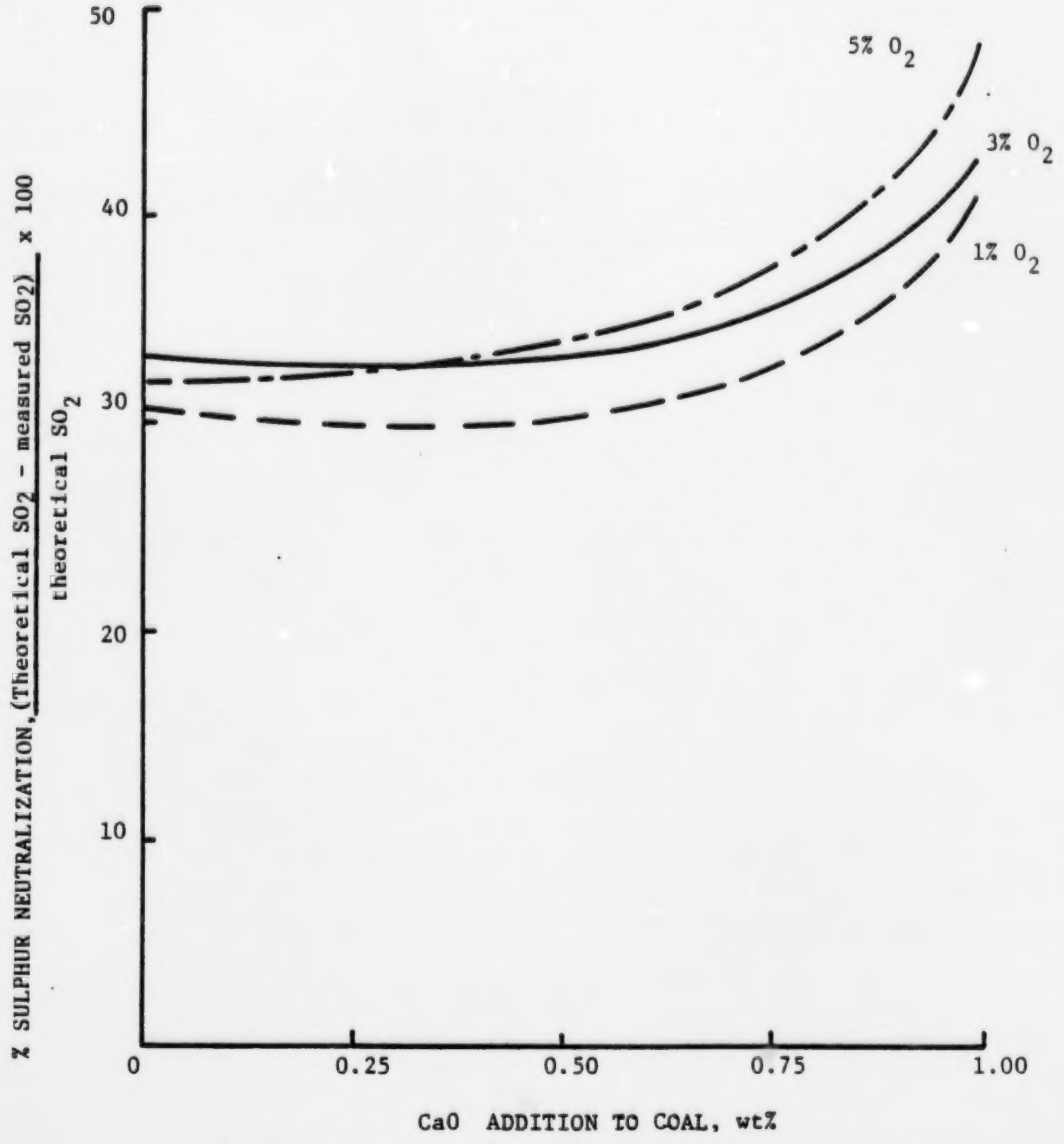

Fig. 2 The effect of lime addition on sulphur dioxide neutralization

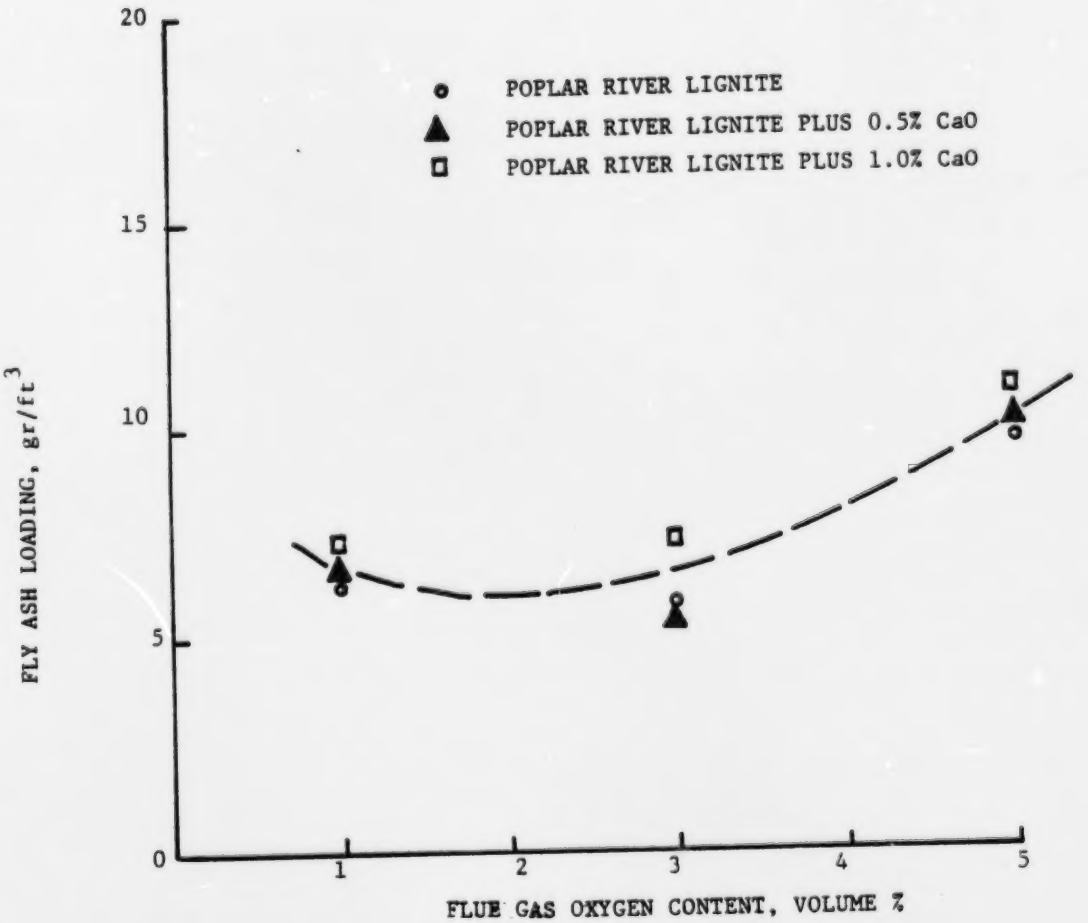

Fig. 3 Fly-ash loadings in the combustion products

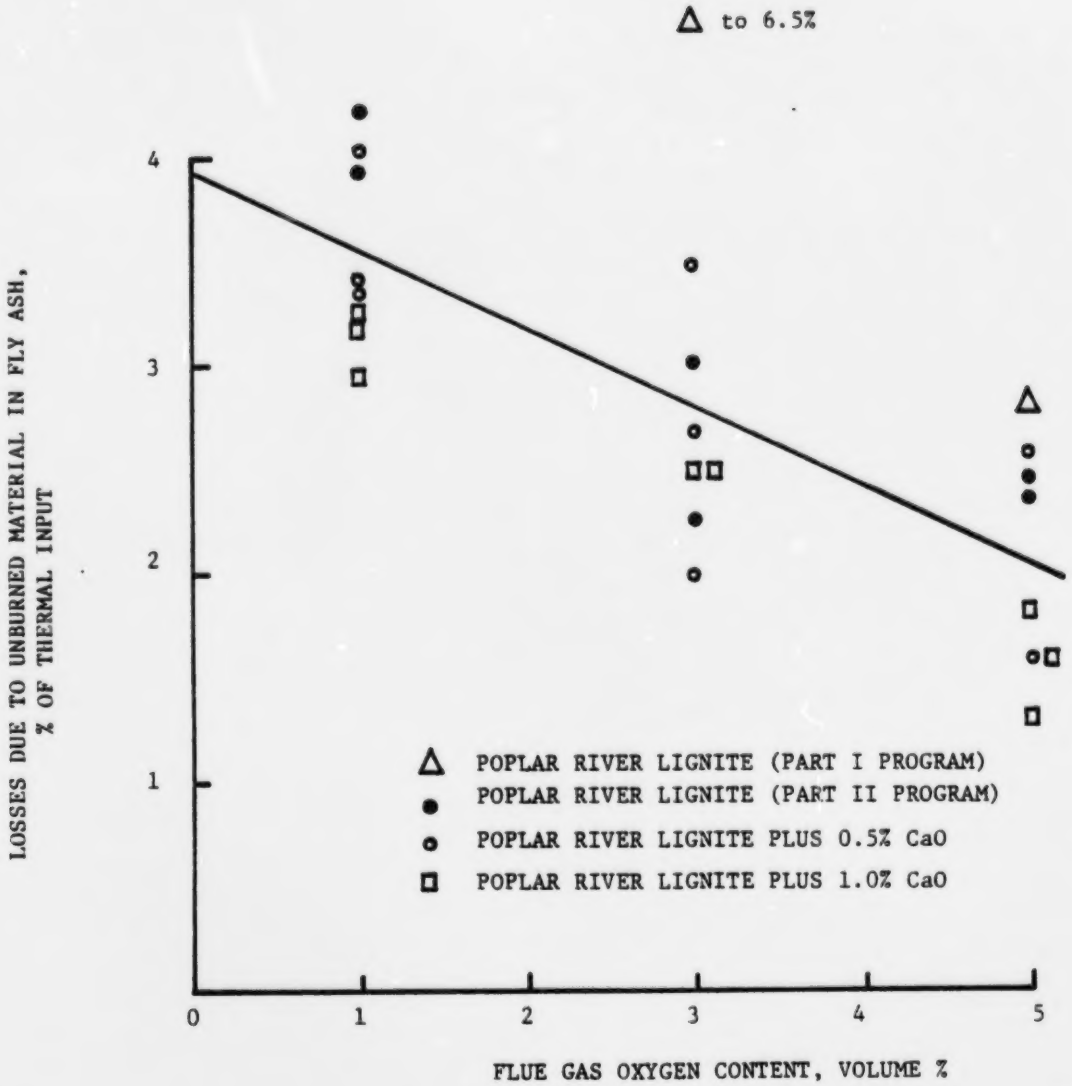

Fig. 4 The effect of flue gas oxygen content on the thermal penalty from carbon in fly ash

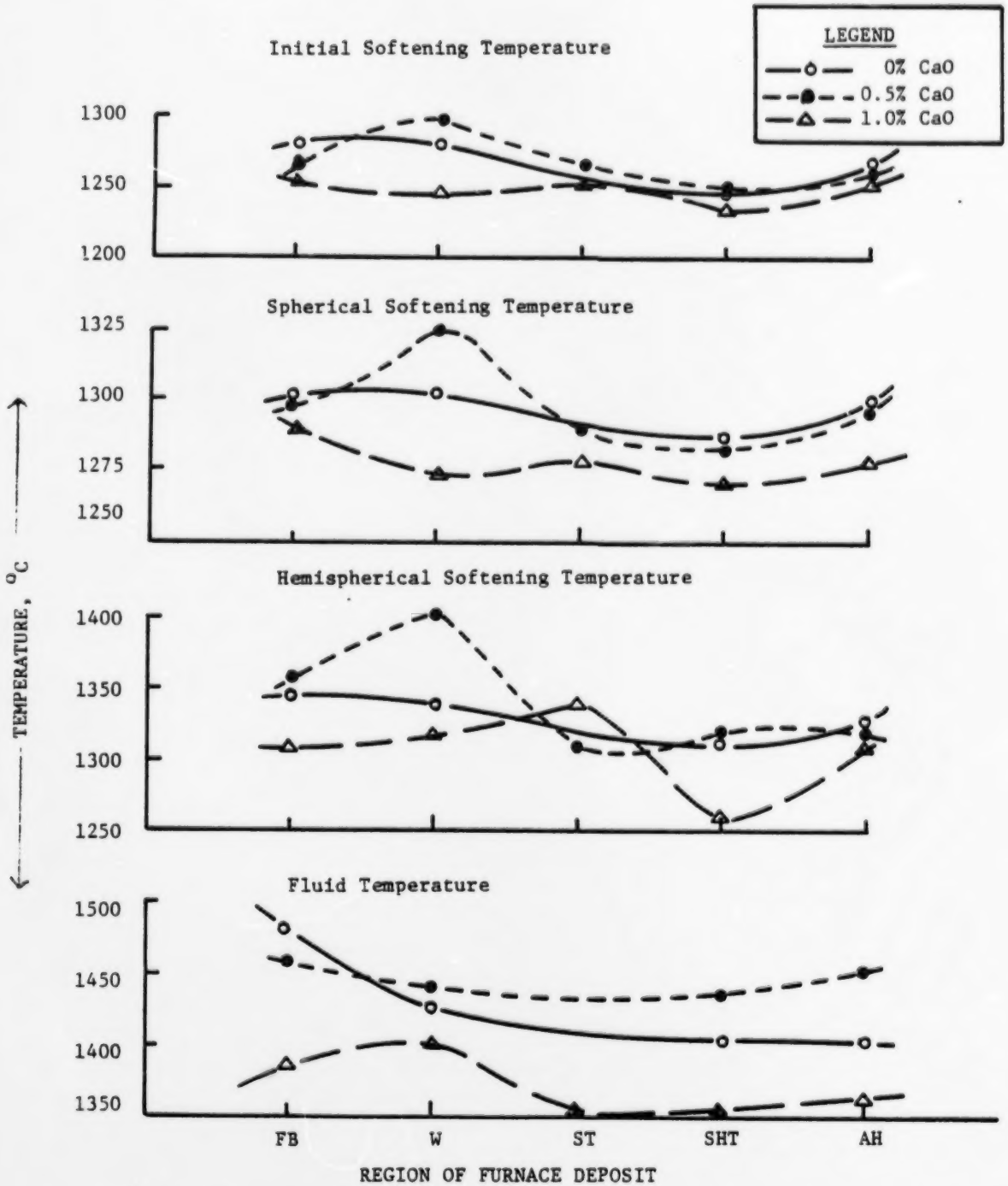

Fig. 5 The effect of lime addition on the fusion characteristics of deposits throughout the boiler